Strategies for implementing placental transfusion at birth: a systematic review

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SYSTEMATIC REVIEW

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Strategies for implementing placental transfusion at birth: A systematic review

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Abstract

Background: Enhanced placental transfusion reduces adverse neonatal outcomes, including death. Despite being endorsed by the World Health Organization in 2012, the method has not been adopted widely in practice.

Methods: We performed a systematic literature search and included quality improvement projects on placental transfusion at birth and studies on barriers to implementation. We extracted information on population, methods of implementation, obstacles to implementation, and strategies to overcome them.

Results: We screened 99 studies out of which 18 were included in the review. The preferred methods of implementation were protocol development (86% of studies) reinforced by targeted education (64% of studies) and multidisciplinary team involvement (43% of studies). Barriers to implementation were mentioned in 12 studies and divided into four categories: general factors such as lack of staff awareness (5 studies) and professional resistance to change (5 studies); obstetrician-specific concerns, including the impact during cesarean (3 studies) and the risk of postpartum hemorrhage (3 studies); pediatrician-specific concerns, including the need for resuscitation (5 studies), risk of jaundice (3 studies), and polycythemia (2 studies); and logistical difficulties. The main strategies to facilitate placental transfusion at birth included effective multidisciplinary team collaboration, protocol development, targeted education, and constructive feedback sessions.

Conclusions: Placental transfusion implementation requires a multidisciplinary approach, with obstetricians, midwives, nurses, and pediatricians central to adoption of the practice. Understanding the obstacles to implementation informs strategies to increase placental transfusion adoption of practice worldwide. We suggest a stepwise approach to implementation and enhancement of placental transfusion into practice.

KEYWORDS

delayed cord clamping, implementation, placental transfusion

1 | INTRODUCTION

At birth, if the umbilical cord is not clamped immediately, blood continues to flow between the placenta and the umbilical cord. This placental transfusion is part of the physiological transition from fetal to neonatal life. It is estimated that up to 30% of the fetal circulating volume is retained in the placenta at birth. Placental transfusion can allow for two thirds of this to re-enter the neonatal circulation.[1,2] Placental transfusion can be enhanced by delayed umbilical cord clamping, umbilical cord milking before clamping, or a combination of these methods.

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Placental transfusion has multiple benefits for both term and preterm infants. In preterm infants, it reduces the number of blood transfusions, incidence of necrotizing enterocolitis, intraventricular hemorrhage, and mortality.[3,4] A recently published meta-analysis calculated a 30% increase in hospital deaths for preterm infants who had their cords clamped immediately after birth.[5] In term infants, placental transfusion increases iron stores, with evidence mounting to show this enhances neurodevelopment throughout infancy.[6-8]

While there was some initial clinical concern with respect to potential increased risk of jaundice requiring phototherapy and increased rates of postpartum hemorrhage, evidence exists to shift these clinicians' perceptions.[3,5,9,10] However, this simple, effective, and cost-free evidence-based practice is not widely adopted, potentially impacting a newborn for life.

Placental transfusion has been gaining international support since 2006, when the International Confederation of Midwives (ICM) and the International Federation of Gynaecology and Obstetrics (FIGO) removed immediate cord clamping from their guidelines on the management of the 3rd stage of labor.[11] In 2014, the World Health Organization published guidelines endorsing delayed cord clamping for a period of 1-3 minutes for all births as part of their essential newborn care pathway.[12] A summary of endorsements from stakeholders can be found in Table 1.

It is important to note that there are very limited data on rates of placental transfusion practice on a global scale, with current evidence from small published surveys and one systematic review indicating adoption of practice is poor.[20-27]

This review aimed to answer the questions: (a) What strategies are used to implement delayed cord clamping or cord milking in different settings around the world? (b) What measures are taken to evaluate and improve delayed cord clamping or cord milking compliance? (c) What obstacles are identified? (d) What methods are described to overcome barriers to implementation of delayed cord clamping? It was anticipated that these findings would be used to propose a stepwise approach to increasing the practice of placental transfusion worldwide.

2 | METHODS

A prospective protocol for this review is published on PROSPERO (CRD42017078455). We performed a systematic literature search by means of the databases: Healthcare Databases Advanced Search (HDAS), E-pub Ahead of Print, In-Process & Other Non-Indexed Citations (OVID), MEDLINE (OVID), MEDLINE Daily (OVID), EMBASE, and The Cochrane Library (Wiley). The search strategy is available in the Supporting Information (online). Search

TABLE 1 A summary of endorsements from stakeholders

Organization	Preterm <37 wk	Term ≥37 wk
WHO 2012, 2014	Delay of umbilical cord clamping for 1-3 min is recommended for all births with simultaneous essential newborn care[12]	
ILCOR 2015	Delay umbilical cord clamping for at least 1 min in both term and preterm infants who do not require resuscitation at birth. Evidence does not support or refute delayed cord clamping when resuscitation is needed[13,14]	
RCOG 2016	Routine early clamping of the umbilical cord no longer recommended. Umbilical cord should not be clamped earlier than 1 min if there are no concerns over cord integrity or the baby's well-being[15]	In healthy term babies, practice "deferred" cord clamping (delay clamping for at least 2 min)[16]
SOGC 2016	Delayed cord clamping by at least 60 seconds is recommended irrespective of mode of delivery[17]	The risk of jaundice is weighed against the physiological benefits of delayed cord clamping
AAP 2017	Endorse recommendations of ACOG 2017[18]	
ACOG 2017	At least 30-60 second delay in cord clamping in vigorous term and preterm infants[19]	

AAP, American Academy of Pediatrics; ACOG, American College of Obstetricians and Gynecologists; ILCOR, International Liaison Committee on Resuscitation; RCOG, Royal College of Obstetricians and Gynaecologists; SOGC, Society of Obstetricians and Gynaecologists of Canada; WHO, World Health Organization

TABLE 2 Mixed Methods Appraisal Tool bias assessment

Study	Are the sources of data relevant to address the research question?	Is the process of analyzing qualitative data relevant? (method, form of data, qualitative analysis)	Is appropriate consideration given to how findings relate to the context?	Is appropriate consideration given to how findings relate to researchers' influence?
Yu (2017)	Yes	Yes	No	No
Armson (2017)	Yes	Yes	Yes	No
Aziz (2012)	Yes	Yes	Yes	Yes
Bacon (2017)	Yes	Yes	No	No
Balakrishnan (2017)	Yes	Yes	Yes	Yes
Beard (2013)	Yes	Yes	No	No
Bolstridge (2016)	Yes	Yes	No	No
Chinnery (2010)	Yes	Yes	Yes	Yes
del Rio (2014)	Yes	Yes	No	No
Faucher (2016)	Yes	Yes	Yes	Yes
Jaques (2015)	Yes	Yes	Yes	Yes
Liu (2017)	Yes	Yes	Yes	Yes
McAdams (2015)	Yes	Yes	No	No
Nathan (2013)	Yes	Yes	No	No
Oddie (2012)	Yes	Yes	Yes	Yes
Perrone (2017)	Yes	Yes	No	No
Rich (2015)	Yes	Yes	No	No
Yee (2015)	Yes	Yes	Yes	Yes

TABLE 3 Summary of studies with data on both implementation and barriers to placental transfusion

Author	Study type (ST) Location (L) Population (P)	Method of implementation	Method of evaluating compliance	Methods of improving compliance and overcoming barriers	Barriers and obstacles	Participants	Results + conclusions
1. Yu, Sullivan & Bates (2017)[23]	ST: Quality improvement L: Single-site NICU, UK P: Preterm <32 wk	Protocol Champions Multidisciplinary team approach	Data collection and analysis of current practice	Simulation training	Limited staff knowledge Logistical issues Financial implications	Obstetricians Neonatologists Nursing staff Pharmacy staff Midwives	Anecdotal evidence and staff feedback suggests success No control
2. Liu (2017)[34]	ST: Retrospective cohort study L: Single-site NICU, USA P: Preterm 22-32 wk	Protocol	Data collection and measuring neonatal outcomes in preprotocol vs postprotocol infant	Quality feedback Continued practitioner education	Cesarean	Maternity unit	Protocol uptake increased progressively over 2 years due to continued practitioner education Cesarean was the only factor independently associated with failing to receive delayed cord clamping (OR: 0.48; CI: 0.25-0.93) Increased hematocrit ($P = 0.007$) and reduced transfusion rates ($P = 0.03$) in postprotocol infants
3. Balakrishnan (2017)[24]	ST: Quality improvement L: 9 NICUs across the USA P: Preterm	Protocol Delivery room toolkit (rhesus roles, equipment checks, debriefing) Multidisciplinary team approach Data collection on practice Feedback	Audit Monthly team meetings Reviewing data + discussing experience	Delivery debriefing Predelivery checklist + improved preparedness	Debriefings revealed barriers in communication among obstetric practitioner Lack of institutional quality improvement experience	Neonatologists Obstetricians Nursing staff	Increased rates of delayed cord clamping from 43% to 67%, role assignment 53% to 98%, debriefing 33%-76% Predelivery preparedness = briefing, scribe, airway, circulation, team leader, radiant warmer, equipment checks Rates of DDC ($P < 0.001$), appropriate thermoregulation ($P = 0.003$), and SPO2 targeting ($P = 0.007$) each saw positive trend with improvements in predelivery preparedness scores

(Continues)

TABLE 3 (Continued)

Author	Study type (ST) Location (L) Population (P)	Method of implementation	Method of evaluating compliance	Methods of improving compliance and overcoming barriers	Barriers and obstacles	Participants	Results + conclusions
4. Faucher (2016)[25]	ST: Quality improvement L: Multisite hospitals, India P: Term infants	Knowledge to action framework Education Simulation training Delivery room signage	Audit Preintervention and postintervention questionnaire on knowledge + beliefs	Feedback sessions Data collection sheets Auditing as performance assessment	Cultural beliefs and social hierarchy—barrier to multidisciplinary team working with compliance expected from midwives Knowledge—incorrect beliefs about immediate cord clamping reducing postpartum hemorrhage, jaundice	Midwives	Significant increase in knowledge and positive beliefs about delayed cord clamping after the workshop Knowledge to action framework for simulation is an effective cross-cultural method for education on evidence-based practice. Practice change after simulation and institutional health policy
5. Rich (2015)[26]	ST: Quality improvement L: Single hospital USA P: Preterm <32 wk	Multidisciplinary team approach Policy Education Simulation videos Exclusion criteria	Not reported	Clear communication guidelines to prompt delivery staff Multidisciplinary team approach Simulation training Time-keeping Delivery room temperature control	Ensuring neonatal normothermia during placental transfusion	Obstetricians Pediatricians Midwives Theater personnel	Great success with implementing a consistent delayed cord clamping process
6. Yee (2015)[28]	ST: Quality Improvement L: Single Hospital USA P: Preterm <32 wk	Policy Education Exclusion criteria	Audit Data collection on predictors of delayed cord clamping	Not reported	Immediate need for resuscitation, suspected abruption, low APGARs Delivery and neonatal factors such as cesarean delivery, suspected abruption, and low 1-min APGAR	Obstetricians Midwives	Increased rate delayed cord clamping 48.2% received delayed cord clamping Maternal characteristics and antenatal were not associated with delayed cord clamping Factors associated with failing to receive delayed cord clamping: • delivery in the first half of the year after protocol was instituted • Having suspected abruption • Low 1-min APGAR

(Continues)

TABLE 3 (Continued)

Author	Study type (ST) Location (L) Population (P)	Method of implementation	Method of evaluating compliance	Methods of improving compliance and overcoming barriers	Barriers and obstacles	Participants	Results + conclusions
7. McAdams (2015)[29]	ST: Quality improvement L: Single hospital USA P: Preterm <37 wk	Educate multidisciplinary team Motivate multidisciplinary Address concerns Policy Measure staff compliance Record outcome data	Quality improvement Outcome data collection Survey on awareness + adherence to delayed cord clamping policy by staff	Education and simulation training Dedicated leadership team Organizational preparedness for change Protocol and clear delayed cord clamping definition Monitoring of outcome data Feedback on performance Promotion of policy according to outcome data Predelivery and postdelivery briefings Clear multidisciplinary team communication	Neonatal: jaundice, polycythemia, delay in resuscitation Maternal postpartum hemorrhage risk Communication: told to do immediate cord clamping by neonatal staff General: lack of staff knowledge	Nurses Nurse Practitioners Respiratory Therapist Midwives Obstetricians Pediatricians Trainees	Increased rate delayed cord clamping 70.7% eligible births had delayed cord clamping length documented 40.7% eligible births actually had delayed cord clamping as per protocol definition
8. Nathan (2013)[31]	ST: Cross-sectional audit L: Single hospital, South Africa P: Term infants	Audit practice by means of a questionnaire Educational presentation Protocol	Re-audit	Protocol Education	35% reported time constraints 30% unaware of benefits 10% pressure from other HCPs 8% postpartum hemorrhage concerns 6% neonatal jaundice concern	Doctors Midwives	Improved delayed cord clamping compliance from 6.8% to 61%

HCPs, health care professionals.

TABLE 4 Summary of studies with data only on implementation of placental transfusion

Author	Study type (ST) Location (L) Population (P)	Method of implementation	Method of evaluating compliance	Methods of improving compliance	Participants	Results + conclusions
1. Bacon (2017)[35]	ST: Retrospective cohort study L: Single-site NICU, USA P: Preterm 24-37 wk	Protocol	Data collection: Measuring hematocrit in preprotocol and postprotocol infants	Not reported	Not reported	Mean hematocrit was higher in neonates that received delayed cord clamping vs those that did not (P= <0.01). Hematocrit was NOT significantly higher in neonates that received delayed cord clamping vs those with no documented reason for exclusion. When delayed cord clamping was not indicated and the infant received it, hematocrit was higher (but not significantly so) than those where it was not indicated and not given
2. Bolstridge (2016)[36]	ST: Retrospective cohort study—pre-QI and post-QI project L: Single-site NICU, USA P: Very low-birthweight infants <1500 g	Policy Multidisciplinary team approach Education champions Addressing concerns Exclusion criteria	Audit Monthly reports discussing experience + re-viewing data	Additional education and support when monthly report indicated individual practitioner "resistance" to delayed cord clamping	Neonatal intensive care nurse specialists Research coordinator Quality and safety coordinator Neonatologist Obstetrician Medical student	Initial 0.7%-73% increase in delayed cord clamping practice after protocol initiated. P = <0.0001 93.7% compliance rate with ongoing monitoring and education Placental transfusion implementation achievable rapidly using quality improvement methodology + multidisciplinary team engagement from a single-center perspective Improved neonatal outcomes: reduced transfusion P = 0.003, decreased need for DR intubation P = 0.002 (but also had protocol to reduce bronchopulmonary dysplasia at same time) and chest compressions P = 0.004, decrease in need for ventilation at any time during hospital admission P = 0.015, decrease in need for continuous positive airway pressure at any time during hospital admission P = 0.015, and decrease in late-onset sepsis = 0.025 No statistically significant increase in jaundice or need for treatment of hypothermia

(Continues)

TABLE 4 (Continued)

Author	Study type (ST) Location (L) Population (P)	Method of implementation	Method of evaluating compliance	Methods of improving compliance	Participants	Results + conclusions
3. Jaques (2015)[27]	ST: Quality improvement L: Single NICU, UK P: Preterm infants	Education Protocol Reminder in neonatal handbook	Audit	Audit with subsequent targeted education Promotion of delayed cord clamping	Obstetricians Pediatricians Midwives	"Increased practice of delayed cord clamping," no control data available
4. del Rio (2014)[30]	ST: Quality improvement L: Single UK hospital P: Extremely low-birth-weight infants	Multidisciplinary team approach Quality improvement Engaging key stakeholders Identify strengths and weaknesses of practice	Data collection	Oral presentations of results Protocol Delivery room practice to wrap, do delayed cord clamping, and blood sampling	Pediatricians Nurses Gynecologist Surgeon	Uncertain No improved outcomes for 11 mo after intervention then began to see change. Unclear cause for improved short-term outcomes for neonates
5. Aziz, Chinnery & Lacaze-Masmonteil (2012)[32]	ST: Quality improvement L: Single hospital Canada P: Preterm <33 weeks	Staff orientation Protocol	Audit	Protocol Reinforcement Education	Obstetricians Pediatricians Midwives	Improved delayed cord clamping, less hypothermia, high initial hemoglobin, less necrotizing enterocolitis. Monthly compliance ranged from 18% to 93% (no further information)
6. Chinnery (2010)[33]	ST: Quality improvement L: Single hospital, Canada P: Preterm	Educational sessions Posters Process mapping Protocol	Audit Chart review	Reinforcement of policy with education	Obstetricians Pediatricians Midwives	Increased rates of delayed cord clamping

terms were term and preterm neonates, delayed cord clamping, implementation, protocols, guidelines, and quality improvement projects without language restrictions.

To better detect quality improvement projects, guidelines, and protocols, the search results for core procedure were crossed with the broad quality improvement facet. We included any studies published in the last 10 years, describing quality improvement projects on placental transfusion at birth but also studies reporting barriers to implementation. The search identified 99 studies, which were checked for duplicates using EndNote. Two independent reviewers screened titles and abstracts for eligibility. Full article analysis was performed on 20 studies meeting the inclusion criteria; studies were then excluded if they lacked qualitative or quantitative data on the impact of a placental transfusion intervention or if they lacked information on the barriers to placental transfusion. Any discrepancies were resolved by consensus with a 3rd reviewer. A PRISMA flow diagram detailing the selection process is provided in Figure S1, Supporting Information. Risk of bias was assessed according to the Mixed Methods Appraisal Tool Version 2011[28,29] (Table 2).

Data on country, publication year, study setting, study type, study aims, population (gestation age, sample size), intervention (methods of placental transfusion, type of professional involved), methods of evaluating intervention, obstacles, and strategies to overcome obstacles were extracted into descriptive Excel tables, producing a summary of review studies (Tables 3-5). This was then analyzed for the frequency of individual implementation and evaluation methods, in addition to obstacles and ways to overcome them.

3 | RESULTS

All 18 publications focused on delayed cord clamping of 30 seconds to 3 minutes as the method of placental transfusion and were conducted in higher- and middle-income countries in the hospital setting. Fourteen studies reported implementation methods (10 quality improvement projects, 3 retrospective cohort studies, and 1 audit).[30-43] Of these 14, 8 included information on implementation methods and barriers to implementation and 6 looked into implementation without offering information on barriers. (Tables 3-5).

The other four studies included in the review provided data on barriers exclusively: a questionnaire across multiple hospitals in Italy addressing placental transfusion practice in the term and preterm population,[44] qualitative research on barriers in preterm infants in the United Kingdom,[17] a questionnaire on attitudes to delayed cord clamping in the United Kingdom,[45] and a quality improvement project identifying barriers to delayed cord clamping to inform a future implementation strategy.[46]

There was a relatively high level of bias in some of the studies included in the review (Table 2). The majority of studies included were conducted on the preterm population, which may limit the ability to generalize a strategy to the term population. Little consideration was given to context, for example, the presence of a pediatrician is common at a preterm delivery, while it is not the norm at term deliveries. Studies were mainly developed in neonatal units in high- or middle-income countries. There is limited information from developing countries and other settings such as community birthing centers and home births. Nevertheless, there was high variability in reporting the results which meant that statistical analysis was not possible.

Our results section summarizes essential components of a placental transfusion strategy, methods of implementation, methods of evaluation, common barriers, and methods to improve compliance and overcome barriers.

3.1 | Essential components of a placental transfusion strategy

To provide a simple overview of the key components of a successful placental transfusion intervention strategy, we assessed for the presence or absence of a method of implementation, evaluation, improving compliance, and overcoming barriers in each study across the review. This allowed for the frequency of each component to be evaluated across studies as a whole.

This showed that 17 out of 18 studies mentioned a protocol, policy, or guideline and the use of the multidisciplinary team or teamwork in a placental transfusion strategy. Education and simulation training were included by 15 studies, whereas audit and data collection were aspects of 14 studies. Feedback on practice was highlighted in 8 studies, whereas 6 included feedback and opinions from staff and 4 included predelivery preparedness.

3.2 | Methods of implementation

Quality improvement projects were the central method of implementation in 12 of the studies. The remaining 2 studies were audits of delayed cord clamping rates, reporting current practice but also suggesting interventions to improve compliance.[38,46] These studies could easily be converted to quality improvement projects if they had been published after their interventions had been put in place.

Thirteen studies reported the health care professionals involved in implementing placental transfusion practice. Eleven studies (79%) included a triad of midwives, obstetricians, and pediatricians. One study reported only the views of obstetricians and midwives, and one study approached midwives alone. There were 6 studies in

TABLE 5 Summary of studies with data only on barriers to the implementation of placental transfusion

Author	Study type (ST) Location(L) Population (P)	Method of evaluating compliance	Method of overcoming barriers	Barriers and obstacles	Participants	Results + conclusions
1. Armson (2017)[37]	ST: Audit L: UK single site P: Preterm <30 weeks	Semi-structured interviews for opinions of advantages, disadvantages, and barriers to delayed cord clamping Observed deliveries	Education Multidisciplinary team approach Simulation training Practical solutions to environmental barriers Feedback on practice	Obstetric concerns: postpartum hemorrhage + general anesthesia Neonatal concerns: neonatal resuscitation Environmental challenges: ensuring normothermia, resuscitation during delay, sterility of theater	Obstetricians Pediatricians Midwives Neonatal nurse	No outcome data on delayed cord clamping rates Four main barriers identified with methods to overcome; no control available
2. Perrone (2017)[38]	ST: Multiple choice questionnaire L: 86 NICUs across Italy P: Term + preterm infants	Statistical analysis of questionnaire responses	Shared decision making within the delivery team Local guideline for delayed cord clamping Improved multidisciplinary team communication Education Protocol	Logistic and pragmatic difficulties: preterm, twin, unaware of practice, considered useless, lack of knowledge about procedures Neonatal concerns: polycythemia, jaundice, hypothermia, infection, delayed resuscitation, hypervolemia, anemia, chorioamnionitis, rhesus alloimmunization Maternal concerns: postpartum hemorrhage, placental disruption, maternal HIV, hepatitis	Not reported	Increased knowledge to include benefits of delayed cord clamping = higher implementation of the practice in both term and preterm deliveries. $P = <0.001$ Statistically significant better implementation of placental transfusion due to efficient communication between teams Availability of a local guideline was associated with a statistically significant enhanced placental transfusion practice in term and preterm babies
3. Oddie & Rhodes (2014)[39]	ST: Qualitative study L: 7 Neonatal units across the UK P: Preterm infants	Semi-structured interviews	Active management during delayed cord clamping and training in practical techniques Senior clinician support/role modeling Multidisciplinary team approach and better communication Protocol development Audit Record keeping aid and predelivery tools	General factors: guideline variability, lack of eligibility criteria Neonatal concerns: absence of a practice to stabilize preterm with cord intact, competing priorities of delayed cord clamping + need for stabilization of infant Professional anxiety (neonatal positioning during delayed cord clamping, sequence of administrating uterotonic drugs)	Obstetricians Pediatricians Midwives Managers	No outcome data on delayed cord clamping rates Identified obstacles and ways to overcome them

(Continues)

TABLE 5 (Continued)

Author	Study type (ST) Location(L) Population (P)	Method of evaluating compliance	Method of overcoming barriers	Barriers and obstacles	Participants	Results + conclusions
4. Beard (2013)[40]	ST: Questionnaire L: Single Hospital UK P: Term infants	Baseline audit Questionnaire on rationale behind lack of delayed cord clamping	Visual aids, aide memoirs	8% of respondents reported lack of knowledge or disagreement with practice 87% of obstetricians + trainees admitted surgical sequence of delivery is automatic, forgot to incorporate a delay before clamping. Experience of obstetrician inversely proportional to ease of incorporation of delayed cord clamping	Midwives Obstetricians	Increased incorporation of delayed cord clamping

which the participants were nurses, either neonatal intensive care nurses, theater personnel, or specialist nurse practitioners.

The most popular method of placental transfusion implementation was a delivery room protocol, policy, or toolkit, reported by 86% of studies. This was followed by education (64% of studies) in the form of didactic teaching sessions (including webinars and grand round presentations), which were often tailored toward each specific health care profession. Education was reinforced by simulation training in 21% of studies, whereas newsletters and intradepartmental signage were used as knowledge reminders by 21% of studies; 43% of studies also focused on engaging the multidisciplinary team to increase awareness of placental transfusion. Placental transfusion practice was actively encouraged through seminars to address clinician concerns in 21% of studies, postdelivery feedback, and debrief on individual placental transfusion practice in one study and the creation of placental transfusion champions seen in two studies.

3.3 | Methods of evaluation

All studies used objective monitoring of placental transfusion practice tools: audit of practice after implementation (57%) and/or collection of impact data (50%) by assessing preintervention and postintervention outcomes. Four studies (29%) also used stakeholder feedback by discussing outcome data at team meetings. To evaluate practice, they used questionnaires assessing individual knowledge and beliefs, but also awareness and adherence to policy. Feedback was used as an adjunct to objective monitoring, whereas audit or outcome data were used exclusively.

3.4 | Common barriers

Multiple barriers to placental transfusion practice were identified across 12 studies. Eight studies reported barriers they had encountered during their implementation process, whereas a further four studies provided information on barriers exclusively (Table 6). Barriers to placental transfusion strategies can be divided into four main domains: general factors, obstetrician-specific concerns, pediatrician-specific concerns, and environmental challenges. General factors preventing practice mainly centered on a lack of staff awareness (5 studies), professional resistance to change (5 studies), difficulty implementing change (4 studies), and a lack of placental transfusion guidance (3 studies). The most common obstetrician-specific concerns were the impact on placental transfusion during cesarean and on the risk of postpartum hemorrhage, each mentioned in 3 of 12 studies. Further concerns were raised with respect to the procedure for placental transfusion in deliveries that deviated from an uncomplicated spontaneous vaginal

TABLE 6 Reported barriers to placental transfusion practice

Barrier	Number of studies out of total mentioning barriers (N = 12)	Number of studies out of those mentioning only barriers (N = 4)	Number of studies out of those mentioning implementations methods and barriers (N = 8)
General factors			
Knowledge of staff	5 (41%)	2	3
Professional resistance to change (obstetrician-automated process of delivery, anxiety, fixed beliefs)	5 (41%)	4	1
Difficulty implementing change/lack of quality improvement experience	4 (33%)	1	3
Lack of guideline/exclusion criteria/ delayed cord clamping definition	3 (25%)	3	0
Cultural beliefs	1 (8.3%)	0	1
Delivery room communication	1 (8.3%)	0	1
Obstetrician concerns			
Postpartum hemorrhage	3 (25%)	1	2
Cesarean	3 (25%)	1	2
Uterotonic drug use	2 (16.6%)	2	0
Placental or cord disruption	2 (16.6%)	1	1
General anesthesia	1 (8.3%)	1	0
Maternal safety	1 (8.3%)	1	0
Maternal infection (HIV/hepatitis C/ chorioamnionitis)	1 (8.3%)	1	0
Rhesus alloimmunization	1 (8.3%)	1	0
Maternal anemia	1 (8.3%)	1	0
Maternal hypertension or eclampsia	1 (8.3%)	1	0
Pediatrician concerns			
Neonatal safety/need for resuscitation	5 (41%)	3	2
Jaundice	3 (25%)	1	2
Polycythemia	2 (16.6%)	1	1
Preterm	1 (8.3%)	1	0
Multiple birth	1 (8.3%)	1	0
Intrauterine growth restriction	1 (8.3%)	1	0
Chronic hypoxia	1 (8.3%)	1	0
Cord blood banking	1 (8.3%)	1	0
Hypervolemia	1 (8.3%)	1	0
Congenital infection	1 (8.3%)	1	0
Environmental challenge			
Logistics (equipment/practical procedures) during delayed cord clamping	3 (25%)	2	1
Delivery room temperature + neonatal hypothermia risk	2 (16.6%)	2	0
Theater sterility	1 (8.3%)	1	0
Financial implications	1 (8.3%)	0	1

implementation. It should include the preferred placental transfusion technique with timings, exclusion criteria, and alternative practice in emergency situations. A protocol allows multiple barriers to placental transfusion to be challenged and is likely to be well received by health care professionals, as demonstrated by a systematic review by Farquhar et al[49] who

delivery. Pediatrician-specific and neonatal concerns focused on the need for neonatal resuscitation and the role of placental transfusion in this context (5 studies). Further concerns with respect to potential adverse outcomes of placental transfusion were also identified: jaundice (3 studies), polycythemia (2 studies), and hypervolemia (1 study). The suitability for placental transfusion in high-risk pregnancies due to fetal characteristics was also discussed. Environmental factors were regularly highlighted as a barrier to placental transfusion with 25% of implementation and/or barrier studies reporting logistical difficulties with equipment during delivery and 27% citing delivery room temperature control and risk of neonatal hypothermia as problems. The logistical difficulties are due to lack of guidance to perform resuscitation with the cord intact but also lack of equipment to facilitate this process while maintaining normothermia and sterility especially during cesarean.

3.5 | Improving compliance and overcoming barriers

Education was the most commonly used method to improve compliance (58%), followed by creation and promotion of a protocol (50%). Audit or data collection and feedback were included by 33% of studies in the effort to improve placental transfusion compliance. Nevertheless, the role of simulation training and efficient multidisciplinary team communication was mentioned in 17% of studies. Several studies included reports of predelivery briefings, debriefings, data collection aids, and creation of leadership teams to improve compliance with adoption of placental transfusion into practice.

Strategies to overcome barriers to placental transfusion centered on improving teamwork. Adopting a multidisciplinary team approach was most frequently mentioned (57% of studies). This was closely followed by improved preparedness for delivery (43% of studies) and assigning roles at delivery (14% of studies). Nearly a third of the studies included debriefing (29% of studies) and improving communication (29% of studies) as methods to overcome barriers. The remaining strategies had significant overlap with methods to implement placental transfusion and included protocol development (29% of studies), feedback and troubleshooting (29% of studies), and education (29% of studies).

4 | DISCUSSION

Our systematic review of 18 studies examining facilitators and barriers to the implementation of placental transfusion found that the preferred methods of implementation were protocol development, reinforced by targeted education and multidisciplinary team involvement. Common barriers included a lack of staff awareness, professional resistance to change, and logistical difficulties, and concerns about the impact of placental transfusion during births complicated by cesarean, postpartum hemorrhage, or the need for newborn resuscitation. The main strategies to facilitate placental transfusion at birth included effective multidisciplinary team collaboration, protocol development, targeted education, and constructive feedback sessions. A significant degree of overlap has been shown between strategies used to implement, evaluate, improve compliance, and overcome barriers to placental transfusion. This is likely due to the variation in baseline practice at each individual institution and the small amount of literature available to provide guidance and examples for successful interventions.

We have found that quality improvement projects are the most popular method to implement or improve compliance to placental transfusion strategies through continual reassessment and their reactive nature. This allows interventions to be tailored to individual institutions and barriers to placental transfusion to be identified and responded to within a short time frame. Furthermore, we have seen that the strengths and weaknesses of a quality improvement project can be studied with a retrospective cohort study, allowing for robust statistical analysis of the intervention.[41-43] Interestingly, Balakrishnan et al[31] found that hospitals using quality improvement methodology had a significantly higher compliance with a new intervention. Their study suggests that there are multiple extrinsic factors that influence the success of interventions. Further exploring these extrinsic factors, Aarons et al[47] highlighted the differences in individual attitudes toward adopting evidence-based practice. They used the same structure as Rogers[48] which used a 5-point scale of innovators, early adopters, early majority adopters, late majority adopters, and laggards. The use of champions for placental transfusion, for example, is a recognized strategy using innovators and early adopters to promote the adoption of an evidence-based practice. In the same study, the authors refer to the "innovation-values fit," describing how the efficacy of innovation will be influenced by the organizational climate and the degree to which the organizational values match those of the individual.[47] They suggest using a "strong implementation climate, ensuring skill in the innovation, providing incentives for its use and removing obstacles to the use of the innovation."[47] These techniques are evident throughout the placental transfusion methods of implementation found in this review. They include the use of a leadership team and champions to support placental transfusion implementation,[17,43] education and simulation training, auditing of practice, data collection, and feedback to and from stakeholders.

Successful placental transfusion interventions rely on a few key components: a protocol, multidisciplinary teamwork, education, audit, and feedback on practice. The development of a placental transfusion protocol is central to

showed that clinicians viewed guidelines as "helpful sources of advice" and "good educational tools" and acknowledged they were "intended to improve quality." A recent cross-sectional survey of 500 obstetricians in the United States has shown that institutional policies influence the implementation of placental transfusion on a national scale, further highlighting their importance and power.[21]

Teamwork and taking a multidisciplinary team approach have been fundamental to the success of increasing placental transfusion practice, reflecting the well-known fact that the success of innovation in health care is proportional to the quality of teamwork.[50,51] Obstetricians, pediatricians, nurses, and midwives are the key multidisciplinary team stakeholders in placental transfusion interventions. Teamwork was promoted in numerous ways; specific strategies included predelivery briefings and debriefings, delivery room role assignment, and simulation training. Thomas et al[52] have shown the success of specific strategies to improve teamwork. The methods to improve neonatal resuscitation efforts include the use of simulation training, recognizing the potential for human error, and improving team communication skills care.[52]

In our review, we recognize the role of stakeholders in placental transfusion adoption of practice which evolves around education and addressing concerns about placental transfusion practice. Education must be holistic and tailored to individual needs, ranging from the evidence base and rationale behind placental transfusion to the practicalities of incorporating it into a delivery. This was mostly achieved using didactic teaching sessions and simulation training. Concerns with respect to placental transfusion can be addressed directly at dedicated meetings or indirectly through education.

An awareness of the common barriers to placental transfusion allows for an intervention to be designed to address these barriers and overcome them. We have shown that there are four main barriers to placental transfusion strategies: maternal, neonatal, environmental, and general staff perceptions. Several reported maternal and neonatal barriers (such as risk of postpartum hemorrhage, jaundice, and polycythemia) highlight the need for better education and promotion of placental transfusion as an evidence-based practice especially as robust evidence exists to refute these concerns.[5] Nevertheless, individual knowledge and belief in an intervention[47] and a widely reported burden of clinician misconceptions about placental transfusion[17,53] have been shown the impact on the likelihood of its success.[47] There is evidence to show resistance to placental transfusion due to the obstetrician's automated process of delivery[45] while performing the cesarean surgical sequence. We believe the delivery room is a key area to focus on behavioral and educational interventions. This review highlights the wider impact of change in delivery room practice, for example, the need for a re-design of the neonatal resuscitation equipment to overcome logistical barriers to placental transfusion. This

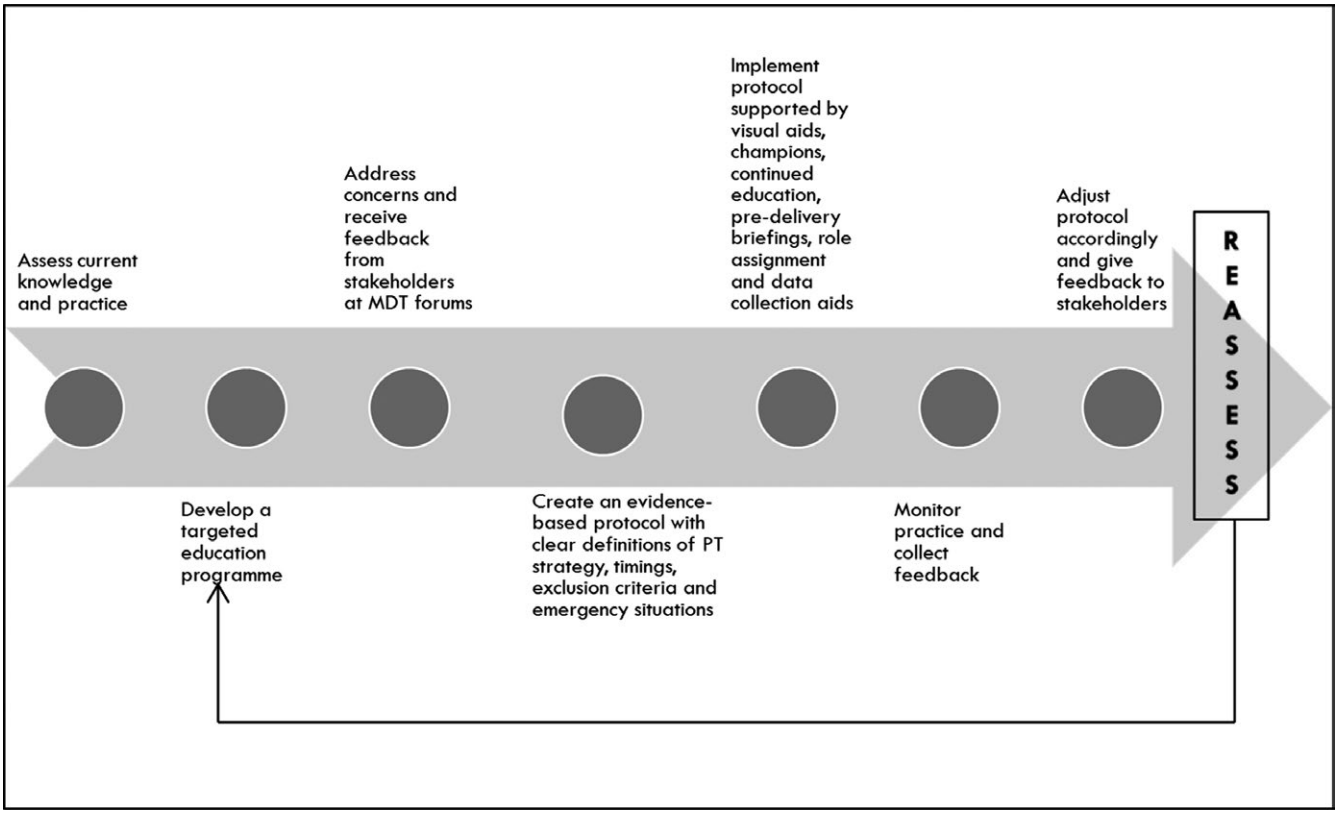

FIGURE 1 Proposed Plan, Do, Study, Act (PDSA) model for placental transfusion quality improvement projects

is due to the lack of equipment to facilitate resuscitation with the cord intact while achieving temperature control and maintaining sterility.

We propose a stepwise approach to setting up an implementation to improve placental transfusion practice according to the fundamental characteristics identified in this review (Figure 1). We suggest the "Plan Do Study Act" methodology for quality improvement project in accordance with guidance from the Institute of Healthcare Improvement.[54] Multiple cycles of the "Plan Do Study Act" model may be used to achieve the full implementation process. We also propose that placental transfusion practice should be included in the data collected by national quality assessment tools, such as the Badgernet in the United Kingdom, or Oxford Vermont Neonatal Database. This will encourage placental transfusion practice at a local level and provide a wealth of data for future studies to assess and better inform policy development and integration in clinical practice.

Ultimately, a possible strategy to increase placental transfusion uptake is to engage the public as key stakeholders. This approach that has been used with great success in campaigns such as the "Back to Sleep" campaign developed to prevent sudden infant death syndrome in the United Kingdom. This strategy has been suggested by one study in our review[6] and evidence exists to show that parents have positive views about placental transfusion at birth.[55]

4.1 | Strengths and limitations

A key strength of our review is that it provides evidence to support a stepwise approach to setting up the implementation of placental transfusion practice following the "Plan Do Study Act" quality improvement methodology. Limitations include the paucity and heterogeneity of published studies on placental transfusion strategies, which prevented robust statistical analysis on the success of alternative methods to implement, evaluate, and promote placental transfusion in clinical practice. Our study was necessarily based on a heterogeneous data set with studies lacking data on some elements of the research question. Also, although the study aimed to comment on implementation on a global scale across all different settings, the lack of publications globally meant that these data only cover the experience in the hospital setting in middle- and higher-income countries and may not be generalizable to lower-income countries.

4.2 | Conclusions

A successful placental transfusion strategy requires a multistep approach, starting with identifying local beliefs about and potential barriers to placental transfusion, followed by assessment of current practice, to devise a targeted education program for key stakeholders. The development of a protocol is vital to placental transfusion implementation, with clear definitions of timings, methods, and exclusion criteria included in the protocol. Teamwork and a multidisciplinary team approach are fundamental to achieving a change in practice. Interventions must also be continually reassessed and supported, to ultimately result in a system change. This can be achieved through the use of feedback to key stakeholders, through debriefing, meetings, and audit. There has been limited research into any potential difference in the impact of placental transfusion on outcomes in low-income countries versus high-income countries. Considering the different pressures faced by infants in these environments, further studies are required to determine the approach to a placental transfusion implementation strategy on a global scale.

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REFERENCES

1. Hutchon DJ. Immediate or early cord clamping vs delayed clamping. *J Obstet Gynaecol*. 2012;32(8):724-729.
2. Moulton L. Challenging current practice: the evidence behind the timing of cord clamping. *Pract Midwife*. 2011;14(5):14, 16.
3. Rabe H, Diaz-Rossello JL, Duley L, Dowswell T. Effect of timing of umbilical cord clamping and other strategies to influence placental transfusion at preterm birth on maternal and infant outcomes. *Cochrane Database Syst Rev*. 2012;8:CD003248.
4. Backes CH, Rivera BK, Haque U, et al. Placental transfusion strategies in very preterm neonates: a systematic review and meta-analysis. *Obstet Gynecol*. 2014;124(1):47-56.
5. Fogarty M, Osborn DA, Askie L, et al. Delayed vs early umbilical cord clamping for preterm infants: a systematic review and meta-analysis. *Am J Obstet Gynecol*. 2018;218(1):1-18.
6. Chaparro CM, Neufeld LM, Tena Alavez G, Eguia-Liz Cedillo R, Dewey KG. Effect of timing of umbilical cord clamping on iron status in Mexican infants: a randomised controlled trial. *Lancet*. 2006;367(9527):1997-2004.
7. Andersson O, Domellof M, Andersson D, Hellstrom-Westas L. Effect of delayed vs early umbilical cord clamping on iron status and neurodevelopment at age 12 months: a randomized clinical trial. *JAMA Pediatr*. 2014;168(6):547-554.
8. Ceriani Cernadas JM, Carroli G, Pellegrini L, et al. The effect of early and delayed umbilical cord clamping on ferritin levels in term infants at six months of life: a randomized, controlled trial. *Arch Argent Pediatr*. 2010;108(3):201-208.

9. McDonald SJ, Middleton P, Dowswell T, Morris PS. Effect of timing of umbilical cord clamping of term infants on maternal and neonatal outcomes. *Cochrane Database Syst Rev*. 2013;(7):CD004074.
10. Ghavam S, Batra D, Mercer J, et al. Effects of placental transfusion in extremely low birthweight infants: meta-analysis of long- and short-term outcomes. *Transfusion*. 2014;54(4):1192-1198.
11. Lalonde A, Daviss BA, Acosta A, Herschderfer K. Postpartum hemorrhage today: ICM/FIGO initiative 2004–2006. *Int J Gynaecol Obstet*. 2006;94(3):243-253.
12. World Health Organization. Regional Office for the Western Pacific. *Early Essential Newborn Care: Clinical Practice Pocket Guide*. Manila: WHO Regional Office for the Western Pacific; 2014.
13. Wyllie J, Ainsworth S, Tinnion R. *Resuscitation and Support of Transition of Babies at Birth*. London: Resuscitation Council (UK); 2015.
14. Wyllie J, Perlman JF, Kattwinkel J, et al. Part 11: Neonatal resuscitation: 2010 International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. *Resuscitation*. 2010;81(1 Suppl.1):e260–e287.
15. Mavrides E, Allard S, Chandraharan E, et al. Prevention and management of postpartum haemorrhage. *BJOG*. 2016;124:e106–e149.
16. Royal College of Obstetricians and Gynaecologists. Clamping of the umbilical cord and placental transfusion. Scientific Impact Paper No. 14. London: RCOG; 2015.
17. Oddie S, Rhodes P. Barriers to deferred cord clamping in preterm infants. *Arch Dis Child Fetal Neonatal Ed*. 2014;99(5):F391-F394.
18. Delayed umbilical cord clamping after birth. *Pediatrics*. 2017;139(6):pii:e20170957.
19. American College of Obstetricians and Gynecologists. ACOG committee opinion no. 684: delayed umbilical cord clamping after birth. *Obstet Gynecol*. 2017;129:e5-e10.
20. Boere I, Smit M, Roest AA, Lopriore E, van Lith JM, te Pas AB. Current practice of cord clamping in the Netherlands: a questionnaire study. *Neonatology*. 2015;107(1):50-55.
21. Leslie MS, Greene J, Schulkin J, Jelin AC. Umbilical cord clamping practices of U.S. obstetricians. *J Neonatal Perinatal Med*. 2018;11(1):51-60.
22. Ibrahim NO, Sukkarieh HH, Bustami RT, Alshammari EA, Alasmari LY, Al-Kadri HM. Current umbilical cord clamping practices and attitudes of obstetricians and midwives toward delayed cord clamping in Saudi Arabia. *Ann Saudi Med*. 2017;37(3):216-224.
23. Nelin V, Ashish KC, Andersson O, Rana N, Malqvist M. Factors associated with timing of umbilical cord clamping in tertiary hospital of Nepal. *BMC Res Notes*. 2018;11(1):89.
24. Lundberg C, Oian P, Klingenberg C. Umbilical cord clamping at birth—practice in Norwegian maternity wards. *Tidsskr Nor Laegeforen*. 2013;133(22):2369-2373.
25. Mivsek AP, Petrocnik P, Skubic M, Skodic Zaksek T, Jug DA. Umbilical cord management and stump care in normal childbirth in Slovenian and Croatian maternity hospitals. *Acta Clin Croat*. 2017;56(4):773-780.
26. Hutton EK, Stoll K, Taha N. An observational study of umbilical cord clamping practices of maternity care providers in a tertiary care center. *Birth*. 2013;40(1):39-45.
27. Matthews KC, Leslie MS. Systematic review of umbilical cord clamping practices worldwide [15A]. *Obstet Gynecol*. 2016;127:15S.
28. Pluye P. Critical appraisal tools for assessing the methodological quality of qualitative, quantitative and mixed methods studies included in systematic mixed studies reviews. *J Eval Clin Pract*. 2013;19(4):722.
29. Pluye P, Hong QN. Combining the power of stories and the power of numbers: mixed methods research and mixed studies reviews. *Annu Rev Public Health*. 2014;35:29-45.
30. Yu C, Sullivan C, Bates S, et al. NeoQIPrem: A multidisciplinary quality improvement project—delivering a perinatal package of evidence-based interventions to optimise the long-term outcome of preterm neonates. *BJOG*. 2017;124:78.
31. Balakrishnan M, Falk-Smith N, Detman L, et al. Promoting teamwork may improve infant care processes during delivery room management: Florida perinatal quality collaborative's approach. *J Perinatol*. 2017;37(7):886.
32. Faucher M, Riley C, Prater L, Reddy M. Midwives in India: a delayed cord clamping intervention using simulation. *Int Nurs Rev*. 2016;63(3):437-444.
33. Rich D. Delayed cord clamping: a multidisciplinary approach. *J Obstet Gynecol Neonatal Nurs*. 2015; 44:S9–S10.
34. Jaques S. *G590 (P) Introducing Delayed Cord Clamping as Routine Practice in a Tertiary Neonatal Unit*. London, UK: BMJ Publishing Group Ltd; 2015.
35. Yee LM, McGuire JM, Khan JY, Gerber SE, et al. Quality improvement of a delayed cord clamping protocol for premature infants in a high volume maternity center. *Reprod Sci*. 2015;22:157.
36. McAdams RM, Backes CH, Hutchon DJ. Steps for implementing delayed cord clamping in a hospital setting. *Matern Health Neonatol Perinatol*. 2015;1(1):10.
37. del Rio R, Baquero C, Herranz N, Izquierdo M, Troyano M, Riverola A. *PO-0673 Improving Quality of care for Elbw in Our Neonatal Unit. An Interdisciplinary Project*. London, UK: BMJ Publishing Group Ltd.; 2014.
38. Nathan H. The practice of delayed umbilical cord clamping (DCC) in a low-resource referral maternity hospital in Kwazulu-natal, South Africa. *BJOG*. 2013;120:316.
39. Aziz K, Chinnery H, Lacaze-Masmonteil T. A single-center experience of implementing delayed cord clamping in babies born at less than 33 weeks' gestational age. *Adv Neonatal Care*. 2012;12(6):371-376.
40. Chinnery H, Aziz K, Lacaze-Masmonteil T. Implementation of a delayed cord clamping (DCC) protocol for preterm infants and delivery room practice. Paediatric and Child. *Health*. 2010;15(Suppl A):16A.
41. Liu LY, Feinglass J, Kern-Goldberger A, Khan Y, Yee LM. 940: Evaluation of implementation of a delayed cord clamping protocol for premature infants in a high volume maternity center. *Am J Obstet Gynecol*. 2017;216(1):S532-S533.
42. Bacon PL, Johnson CT, Frank K, Diaz J, Bullard JE, Jelin AC, et al. Implementation of delayed cord clamping in premature neonates. *Reprod Sci*. 2017;24:246.
43. Bolstridge J, Bell T, Dean B, et al. A quality improvement initiative for delayed umbilical cord clamping in very low-birthweight infants. *BMC Pediatrics*. 2016;16(1):155.
44. Perrone B, Ghirardello S. Placental transfusion strategies in Italy: a nationwide survey of tertiary-care delivery wards. *Am J Perinatol*. 2017;34(07):722-728.
45. Beard M. PL.65 Deferred clamping of the umbilical cord: neural programming in the surgeon as a barrier to change. *Arch Dis Child Fetal Neonatal Ed*. 2013;98(Suppl. 1):A72-A73.

46. Armson A, Sullivan C, Woodman A, Bates S, et al. Delayed cord clamping at preterm delivery to optimise outcome—what are the barriers to implementation? *BJOG*. 2017;124:73.
47. Aarons GA. Measuring provider attitudes toward evidence-based practice: consideration of organizational context and individual differences. *Child Adolesc Psychiatr Clin*. 2005;14(2):255-271.
48. Rogers E. *Diffusion of Innovation*, 4th edn. New York, NY: The Free Press; 1995.
49. Farquhar CM, Kofa EW, Slutsky JR. Clinicians' attitudes to clinical practice guidelines: a systematic review. *Med J Australia*. 2002;177(9):502-506.
50. Hoegl M, Gemuenden HG. Teamwork quality and the success of innovative projects: a theoretical concept and empirical evidence. *Organ Sci*. 2001;12(4):435-449.
51. Mills PD, Weeks WB. Characteristics of successful quality improvement teams: lessons from five collaborative projects in the VHA. *Joint Comm J Qual Saf*. 2004;30(3):152-162.
52. Thomas EJ, Williams AL, Reichman EF, Lasky RE, Crandell S, Taggart WR. Team training in the neonatal resuscitation program for interns: teamwork and quality of resuscitations. *Pediatrics*. 2010;125(3):539-546.
53. Jelin AC, Kuppermann M, Erickson K, Clyman R, Schulkin J. Obstetricians' attitudes and beliefs regarding umbilical cord clamping. *J Matern Fetal Neonatal Med*. 2014;27(14):1457-1461.
54. Dixon-Woods M, McNicol S, Martin G. Ten challenges in improving quality in healthcare: lessons from the Health Foundation's programme evaluations and relevant literature. *BMJ Qual Saf*. 2012;21(10):876-884.
55. Ayers S, Sawyer A, During C, Rabe H. Parents report positive experiences about enrolling babies in a cord-related clinical trial before birth. *Acta Paediatr*. 2015;104(4):e164-e170.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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